A Study Of Acoustic Fluctuations From Basin-Scale Pulse Transmissions

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LONG-TERM GOAL

The long-term goal of this research is to develop our understanding of long-range oceanic pulse propagation through random sound speed fields, like those caused by internal waves, so that we can use acoustic fluctuations like temporal, vertical, and horizontal coherence to infer average internal-wave spectral parameters.

OBJECTIVES

The scientific objective of this work is to develop analytical expressions for temporal, vertical, and horizontal coherence of the acoustic field as a function of internal-wave model parameters. Analytical results for these second moments are important because they eliminate the need for time-consuming Monte-Carlo runs and they allow an efficient treatment of the inverse problem[3]. A key element of this work is understanding the limits of geometrical optics (GO) at frequencies of order 75-Hz.

It has been shown that acoustic fluctuations from energy which has ensonified the upper few hundred meters of the ocean cannot be explained using the Garrett-Munk (GM) internal wave model[3], so a secondary, oceanographic objective of this work is to explore upper ocean internal-wave models.

APPROACH

We are analyzing data from the Acoustic Thermometry of Ocean Climate (ATOC) North Pacific network, and the North Pacific Acoustic Laboratory (NPAL). The ATOC data consists of 8 months of intermittent 75-Hz pulse transmissions from a bottom mounted source on Pioneer seamount (off San Francisco), which were received on two, 40 element moored vertical line arrays (VLAs) one located off the island of Hawaii and one located near Kiritimati. For NPAL an ATOC source was deployed off Kauai and has been transmitting intermittently since July 1998 to four, 20 element VLAs and one 40 element VLA arranged in a billboard configuration and located on Sur Ridge off Monterey. The intermittency of the transmission schedule is due to marine mammal research and a transmission period consists of 20 minute broadcasts every 4 hours for 4 days. In particular we are looking at the acoustic fluctuations of the early ray-like arrival pattern and we are quantifying travel time variance, temporal, vertical, and horizontal coherence as a functions of Julian day.

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We are also collecting in-situ observations of internal waves in the upper 800m of the ocean at two locations along the NPAL transmission path.

In parallel we are developing computer codes to evaluate acoustic coherence functions utilizing assorted internal-wave models. The coherence calculation involves evaluating the phase structure function *D* between two points (1) and (2) which may be separated temporally, vertically, or horizontally; that is

$$D(1;2) = \langle (\delta\phi(1) - \delta\phi(2)^2 \rangle \qquad (0.1)$$

Where $\delta\phi$ is the phase fluctuation computed using GO. The coherence function is expressed in terms of *D* by

$$\langle \psi(1)\,\psi^*(2) \rangle = \exp(-D(1,2)/2). \qquad (0.2)$$

WORK COMPLETED

We have finished analysis of the ATOC, Acoustic Engineering Test (AET)[1,2] which transmitted pulses over a 6 day period from R/P FLIP located on Jasper Seamount 250 nm S-SW of San Diego to a 20 element VLA located off Hawaii. We have calculated the travel time variance, pulse time spread, time and depth coherence functions, intensity variance and intensity probability density functions for resolved wave fronts. We have also made predictions of these quantities based on the GM internal wave model and we have compared them to the observations. We have also explored extensions of the current ocean acoustic wave propagation through random media theories which treat CW or very narrowband signals to fully broadband situations like the ATOC signals.

RESULTS

From the AET data analysis we have made the surprising discovery that the transmissions were in the unsaturated or nearly partially saturated wave propagation regime. This is in strong contradiction to a fully saturated prediction based on calculations of Λ and ϕ[1]. Furthermore narrowband estimates of the pulse time spread, τ_0, are different from the observations by a factor of 100[1]! These results suggest that the scattering is much weaker than anticipated and that GO might be valid. Calculations of pulse acoustic wave scattering based on the Born approximation show that the Λ parameter is clearly inappropriate for broadband signals and that the significant scale lengths of the acoustic field are much smaller than the Fresnel zone. Comparisons between predicted and observed coherences (the predictions were made using Eqs 0.1 and 0.2, and the GM internal wave model) for the AET (after correcting for the appropriate GM energy level) show predicted coherences to be too low of order 50 to 100 percent. If our assumptions of GO are correct and since we had already adjusted for the GM energy level then other parameters of the GM model need to be adjusted. This is heading down the internal-wave tomography path.

IMPACT/APPLICATION

This work has tremendous impact for basin-scale ocean acoustic tomography which relies on weak scattering from internal waves and the GO approximation. The observation of unsaturated or nearly partially saturated propagation for the AET suggest that the internal wave travel time bias is of order the observed pulse time spread which was 0 to 5 ms rms. These numbers are much smaller than the travel time variability which was 15 ms rms. The observation of weak scattering for the ray-like arrivals also has obvious Navy signal processing implications. At the same time the AET results reveal our inability to predict wave propagation regime for long-range pulse propagation experiments. While the observations suggest the applicability of GO more numerical test should be made; namely Eqs 0.1 and 0.2 need to be examined. If Eqs 0.1 and 0.2 are accurate then we can attempt to apply them as the forward model for our internal-wave tomography inverses.

TRANSITIONS

None at this time.

RELATED PROJECTS

1. Effects of small-scale ocean fluctuations on ocean-acoustic transmission, Stanley M. Flatt .
2. North Pacific Acoustic Laboratory; Peter F. Worcester and Robert C. Spindel
3. Ocean acoustic observatories: Data analysis and interpretation; Peter F. Worcester, James A. Mercer, and Robert C. Spindel

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2. P. F. Worcester, B. C. Cornuelle, M. A. Dzieciuch, W. H. Munk, J. A. Colosi, B. M. Howe, J. A. Mercer, R. C. Spindel, K. Metzger, T. G. Birdsall, and A. B. Baggeroer, “A test of basin-scale acoustic thermometry using a large-aperture vertical array at 3250-km range in the eastern North Pacific Ocean”, Accepted 1998, J. Acoust. Soc.
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3. J. A. Colosi, “A Review of recent results on ocean acoustic wave propagation in random media: Basin scales”, Accepted 1998, IEEE J. Oceanic Engineering.